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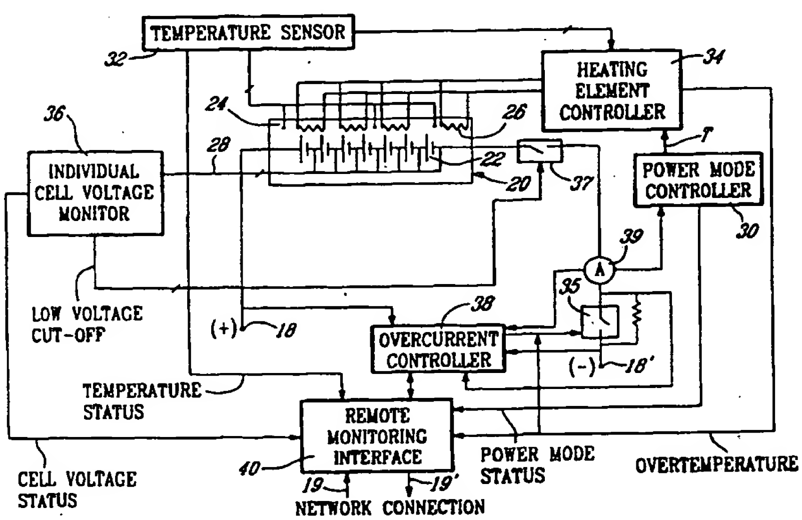

(57) Abstract

A battery controller system for a metal and solid electrolyte battery, such as a lithium-polymer battery has temperature sensors arranged to detect a temperature of cells in the battery, heating elements arranged to heat the cells, a heating element controller receiving signals from the temperature sensors and controlling a current supplied to the heating elements so as to maintain each one of the cells at a predetermined temperature, and a power mode controller detecting a demand for power from the battery and setting the predetermined temperature in response to a level of power to be supplied from or to the battery. The power mode controller sets at least a floating temperature, a charging temperature, and a power supply temperature. The controller also has voltage sensor detecting a voltage of each one of the cells during use, and determines whether any one of the cells is susceptible to damage by continued use. The battery is disconnected from the power connection in response to determination that one of the cells may be damaged.

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LITHIUM-POLYMER TYPE BATTERY AND CONTROL SYSTEM

Field of the Invention

The present invention relates to a battery controller and monitoring system for a solid state, polymer electrolyte battery operated at a controlled elevated temperature, such as a lithium-polymer battery. More particularly, the invention relates to an uninterrupted power supply (UPS) battery controller.

Background of the Invention

In recent years, rechargeable batteries are more and more widely used. In the middle and long term, they provide an economic way of providing electrical energy storage and find their applications in different fields of industry.

One of the applications wherein rechargeable batteries are used is the field of Uninterrupted Power Supplies (UPS) which are used for today's computers and telecommunication equipment that has to be continuously powered, even in the case of a power failure. A UPS system comprises rechargeable batteries that are in a charging process when the grid power is available, but the batteries start providing electrical power to the electronic equipment connected to it, as soon as a power failure is detected.

Such UPS systems need battery controllers in order to improve their performance and lifetime. A battery controller controls the process of charging the batteries, and monitors the discharge state of the batteries. In some UPS systems, temperature sensing of the batteries being charged is carried out so as to control charging or battery by-passing. In conventional UPS systems for large computer systems or telecommunications equipment backup power supplies, lead-acid batteries are normally used as the energy storage medium.

New battery techonologies have been developed which promise improved energy storage capacity, energy storage density and power supply/charging rate level characteristics over the traditional lead-acid battery. For example, metal/metal-hydride batteries have proven to be an efficient source of energy storage, and commercial forms of such batteries have proven successful, such as Ni-MH batteries.

One form of new battery technology which promises very good energy storage characteristics is the lithium-polymer battery (LPB). This battery has a solid electrolyte and stores or releases energy as a result of a phase change in the storage medium without producing any vapor. Energy density (W•h/l) and specific energy (W•h/kg) of LPB is very high compare to other battery technology.

However, the LPB operates at temperatures elevated above room temperature, and has power delivery or charge acceptance characteristics which depend on temperature. The open circuit voltage of LPBs also vary greatly as a function of discharge, namely the cell voltage may decrease by some 10% to 30% (eg. from 3.2V to 2.0V) as the cell is discharged from full charge to minimum charge. It is therefore not feasible to make use of conventional LPBs in applications requiring reliability such as UPS which operate in the field under conditions which may vary from relatively stable indoor conditions to extremely unstable outdoor conditions in different climatic conditions.

Summary of the Invention

It is a broad object of the invention to provide a battery controller for a solid-state battery, such as an LPB, which is able to manage the needs of the battery operation so that the battery can be reliably installed and used in the field.

It is a first object of the invention to provide a battery controller which maintains the battery at an appropriate temperature for the desired mode of operation of the battery.

It is a second object of the invention to provide a battery controller which monitors individual cell voltage and discontinues supplying current to or from the battery when the cell voltage indicates that the continued supply of current to the battery may permanently damage a cell within the battery.

It is a third object of the invention to provide a battery controller for a solid-state battery, such as an LPB, which monitors both temperature and current levels to be able to detect an over current condition and discontinue full supply of current.

It is a fourth object of the invention to provide a battery controller including telecommunications means for communicating battery performance evaluation data to a service center or user.

Accordingly, it is an object of the present invention to provide a Network Powering System (NPS) Battery Controller for controlling and monitoring the operating status and working conditions of lithium-polymer batteries or other batteries having similar temperatures and current control needs.

It is another object of the present invention to provide a method of controlling the performance of a battery system by adjusting its temperature depending of the status of the battery and of the task currently performed by the battery. The internal temperature of the batteries is adjusted by the battery controller depending on the battery operation mode and set to particular temperatures depending on the type of application. In a preferred embodiment of the present invention, two particular temperatures are used, specifically 40 °C and 60 °C and the battery controller set the batteries internal temperature to be one of these two temperatures depending on the batteries operation mode.

It is another object of the present invention to provide a method of remote controlling the battery controllers over a network from a data acquisition, control and monitoring station, such as a personal computer. Various tasks may be performed from this remote station, that may be, eventually, the same tasks a local administrator could perform locally, on the battery controllers, in order to change or set up their settings.

In a preferred embodiment of the present invention, the battery system controlled by the battery controller is a set or string of nine cells connected in series, having a maximum voltage of 3.1 V/cell, thus providing a maximum battery voltage of 28 V. However, other sets of batteries having different number of internal cells, with various voltages, may also be controlled by the present battery controller.

According to the invention, there is provided a battery controller system for a metal and solid electrolyte battery having a number of cells housed arranged in a housing, comprising a plurality of temperature sensors arranged to detect a temperature of said cells, a plurality of heating elements arranged to heat said cells, a heating element controller receiving signals from said temperature sensors and controlling a current supplied to said heating elements so as to maintain each one of said cells at a predetermined temperature, and a power mode controller detecting a demand for power from the battery and setting said predetermined temperature in

response to a level of power and/or an amount of energy to be supplied from or to said battery, the power mode controller setting at least a floating temperature, a charging temperature, and a power supply temperature.

Preferably, the heating elements comprise sheet heating elements provided between flat prismatic cells. More specifically, the heating elements preferably comprise plastic sheets having at least one printed circuit resistive heating element thereon. The plastic sheets are preferably made of Kapton™ Also preferably, the temperature sensors are located at extremities of the cell stack and near a middle of the stack, and the heating elements are provided between at least every other one of the cells, the heating element controller controlling a supply of current to the heating elements independently for the extremities and the middle of the cell stack.

According to the invention, there is also provided a battery controller system for a metal and solid electrolyte battery having a number of cells connected in series and a power connection comprising a voltage sensor detecting a voltage of each one of the cells during use, means for interpreting the detected voltage and for determining whether any one of the cells is susceptible to damage by continued use, and means for disconnecting the battery from the power connection in response to determination that one of the cells may be damaged.

Brief Description of the Drawings

The invention will be better understood by way of the following detailed description of a preferred embodiment with reference to the appended drawings, in which:

Figure 1 is a perspective view of a battery unit according to the preferred embodiment;

Figure 2 is a schematic block diagram of the control system for the battery unit according to the preferred embodiment;

Figure 3 is a schematic side view of a part of a lithium-polymer battery according to the preferred embodiment;

Figure 4 shows a heating element for positioning between cells in the battery according to the preferred embodiment;

Figure 5 shows a general representation of the NPS Battery System;

Figure 6 shows a battery controller state diagram, wherein the arrows going from one state to another represent the conditions needed to be satisfied for changing the controller state of operation;

Figure 7 illustrates the NPS controller entity relationship diagram;

Figure 8 shows the NPS controller block diagram;

Figure 9 shows the NPS controller data flow diagram;

Figure 10 illustrates the software block diagram of the present controller.

Figure 11 illustrates how a remote acquisition, control and monitoring station can control a plurality of battery controllers over a network;

Figure 12 shows an example of configuration wherein a number of battery controllers are employed for controlling and monitoring a plurality of batteries and wherein these controllers are remotely monitored by a remote surveillance station.

Detailed Description of the Preferred Embodiments

In a preferred embodiment of the present invention, the battery is used in a network powering system (NPS) rechargeable battery string for providing an Uninterrupted Power Supply (UPS) for telecommunications or electronic equipment. The NPS battery is equipped with a controller based circuit card assembly to control and monitor the battery operating status and working conditions. This electronic controller and the method it uses for controlling the batteries is one of the main objects of the present invention. It has to be noted that the battery and the battery controller system according to present invention is not limited to NPS or UPS applications.

The battery 15 contains lithium-polymer cells having a construction which is known in the art, and in particular is known from a variety of Applicant's own published patent applications, granted patents, and publications. The battery housing 17, as illustrated in Figure 1, is designed for installation in the field and is a self-contained unit with a rugged plastic outer shell. The housing shell is hermetically sealed to protect the lithium-polymer battery from exposure to air. Two terminal posts 18,18' protrude from the housing 17 and provide 25V direct current (DC). Alternatively for NPS applications, it is possible to configure battery 15 to provide 50Vdc. Two network cable connector jacks 19 and 19' are provided in the housing 17

for connecting a communications interface of the battery 15 in a chain with a communications network and other batteries.

Within the battery 15, a plurality of lithium-polymer cells 22 are connected in series to build up the desired supply voltage, for example, nine (9) cells having a voltage which varies (depending on the charge state) between 2.0 and 3.2 volts may be connected in a series 20 to provide a nominal 24 V. The battery 15 may contain a single such series 20, depending on the size of the individual cells 22, and on the desired supply current and storage capacity characteristics of the battery 15. In Figure 2, there is shown a single series 20 of cells 22 contained in the housing 17, however, two mechanically separate series 20 may be connected electrically in series to provide a higher supply voltage, or alternatively, two (or more) mechanically separate series or stacks may have individual cells connected in parallel pairs (or n-tuples) to provide greater energy storage while keeping a same supply voltage. Each cell 22 is formed of a flat roll or prism stack of lithium-polymer battery film. The construction of such cells is known in the art, and may also take the form of individual sheets, cylindrical rolls, flat rectangular rolls, folded stacks, etc. The series 20 of cells 22 is insulated within housing 17 to prevent thermal heating loss.

As illustrated in Figure 3, the cells 22 are electrically connected together in series and arranged in a chain as a long stack. In the preferred embodiment, the series of cells 20 are compressed together mechanically, as is known in the art of lithium-polymer batteries, to provide a minimum pressure of about 15 psi (100 kPa). At regular intervals between the cells 22, heating elements 26 are inserted as shown in Figures 3 and 4 for the purposes of heating the cells 22 to the desired operational temperature.

Temperature control is important in a lithium-polymer battery. Conventional back-up batteries do not require heating or cooling for normal operation. The lithium-polymer battery used in the preferred embodiment need to operate at a temperature of 40°C to begin operating (independently of the ambient temperature). The temperature needs to be raised to 60°C to be able to deliver (or during charging, to accept) greater power. Furthermore, as the battery is discharged, the battery temperature must be increased if the power outage is maintain for 30 minutes or greater.

As illustrated schematically in Figure 2, temperature sensors 24, such as thermistors or another type of temperature sensor, detect the temperature of the battery at a number of points. The method of conversion of the resistances of the temperature sensors into temperature values by the temperature sensor circuit 32 is well known in the art. A heating element controller 34 analyzes the temperature values and adjusts the duty cycle of operation of the heating elements 26 to maintain the cells 22 at the desired temperature. The heating elements 26 in the preferred embodiment are electrically driven and are provided as printed resistive elements on plastic film, e.g. made of Kapton™, (see Figure 4) and are electrically insulated from the cells 22. The leads on heating elements 26 are located at the top thereof, and the temperature sensors 24 are located close to one of the leads to detect a maximum temperature. The heating elements 26 according to the preferred embodiment are light-weight, do not take up much volume, have good thermal transfer properties, and do not generate any substances which could contaminate the inert air of the battery, especially when used at high temperatures. The heating elements operate at the nominal operating voltage of the battery so that the heaters 26 can be used from a cold start to warm up the cells 22. The heating elements 26 may be positioned in between every cell 22, between every other cell 22, or even more sparsely. The advantage of using heating elements between the cells 22 is that the heat generated is directly transferred to the body of the cells 22. The mechanical compression of the cells ensures excellent thermal contact. It is important to provide heating which avoids generating "hot spots" and is able to heat the battery to the desired temperature quickly and efficiently.

The heat loss of the rectangular prism 20 of cells 22 connected in series is greater at the extremities than in the middle of the bundle. For this reason, it may be desirable to provide more heaters at the extremities of the series 20 than in the middle In the preferred embodiment, separate temperature control over each end and the middle section of the stack or bundle of cells is provided. The maximum allowable temperature variation within the series 20 according to the preferred embodiment is ±2°C. In the preferred embodiment, there are six temperature sensors (representing the three zones) located to monitor the series 20 temperature at the ends and in the middle. The number of temperature sensors are doubled to improve reliability.

The desired temperature is determined by a power mode controller 30. Each mode has a predetermined temperature setpoint value. In the "sleep" mode, the temperature control system is inactive, and this mode may be considered to the a "shelf stand-by" mode. In the "stand-by" mode, rectifier voltage has been detected and a decision is made to move into the "cold mode" after a brief period of time. In the "cold mode", the battery control system uses rectifier power to supply the heating element controller to heat the battery cells to 60°C. Once the 60°C temperature is reached, the system switches to "charging mode" in which the power switch 35 closes and the battery is charged from the rectifier until the voltage is equal. If the rectifier fails during charging, the system switches to the "hot power failure", and the battery is kept at 60°C. If the rectifier does not fail before completion of charging, the system enters the "floating" mode. In this mode, the temperature is allowed to drop to 40°C, and the battery is ready to supply power as soon as a rectifier failure occurs. When a rectifier failure occurs, the system enters the "power failure" mode and maintains the battery temperature at 40°C. At this temperature, the LPB is able to deliver 50% of its energy capacity. Under normal discharge in the preferred embodiment, the battery 15 will last at least 30 minutes at 40°C. After 30 minutes, the battery enters "hot power failure" mode in which discharge continues and the battery temperature is raised to 60°C. At 60°C, the battery in the preferred embodiment is able to supply all of its energy capacity. Maintaining the battery at a lower temperature at which full energy capacity is not available in the floating state prolongs battery life. By increasing the battery temperature, as required in the event that the power failure continues, full energy capacity and long battery life are achieved.

The power mode controller detects the voltage at the terminals 18,18', as well as the current supplied using a reading from a current detector 39. The controller 30 outputs a temperature set signal to heating element controller 34 to set the temperature to the appropriate temperature for current mode. In the simplified temperature control scheme according to the preferred embodiment, the temperature is maintained at 40°C during a first 30 minutes of normal back-up use, and then the battery temperature is raised to 60°C to permit continued power supply even though the battery has been partly discharged. The controller 30 could alternatively raise the temperature of the battery progressively as the battery energy is discharged. The control over switching

between the cold mode and the stand-by mode may also be operator determined using the interface 40.

The control system according to the preferred embodiment is provided with a number of safety and operation monitoring features. Firstly, the voltage of each cell 22 is measured using a bus 28 and a cell voltage measuring and monitoring circuit 36. In the case of lithium-polymer batteries, an individual cell may lose its capacity to supply power at a certain point in its discharge, and consequently its voltage may drop more rapidly. The voltage of individual cells can be measured and compared to an absolute scale (i.e the voltage in volts), or the voltage measured may be compared to the other cells. As soon as it is detected that a single cell 22 has a voltage significantly lower that an acceptable value, eg. either 2.0V or a given percentage of the other cell voltages, the circuit 36 decides to disconnect the series of cells 20 by opening a relay switch 37. By stopping continued use of the series of cells 20, damage to the individual cell 22 having the low voltage is prevented. However, a full recharge of the series followed by equalization of cells 20 will allow the low voltage cell 22 to recover and be useful for further cycles. Equalization of the battery means that the individual cells are charged to the same voltage. For this purpose, the individual cell voltage monitor has a special active charge mode for supplying current onto bus 28 for charging individually each cell 22 until they reach a common voltage, eg. 3.2V.

Secondly, current supplied by the battery is monitored using a sensor 39. Overcurrent, typically resulting from an external short circuit condition, is detected and controller 38 opens relay switch 35. If there is only one series 20 in the battery 15, switch 37 and 35 will be the same switch. Controller 38 detects the voltage at the terminals 18,18', and when the voltage returns to be above zero, switch 35 is closed and power supply may resume. In this way, cycling of the power switch 35 is prevented.

Thirdly, the heating element controller 34 detects an overtemperature condition, for example a temperature exceeding 80°C, and it will disconnect the series of batteries 20 from terminals 18,18' until the temperature drops to a value of 40°C. In addition to electronic control of the electric heaters to prevent overtemperature, a thermal fuse may be provided to disconnect the power supply from the heating

elements 26 when the battery temperature reaches 93°C. The thermal cutoff fuse is located at a point most likely to be the hottest in the housing. The thermal fuse may comprise an NTE-8090 manufacturer NTE Electronics. Extreme overtemperature is dangerous since the Lithium could liquefy (at 180°C) and become volatile if exposed to air.

The remote monitoring interface 40 collects voltage, current, temperature and power mode data for the purposes of compiling performance and operation reports. The interface 40 may be directly connected via a modem to a telephone line at the telecommunications equipment site for the purposes of sending electronic status reports. Status report can be sent at regular intervals, as well as whenever a problem is detected. Remote access to interface 40 can also be achieved, not only when reports are being sent, but also upon remote request, ie: the interface 40 may provide information or accept commands sent via the telecommunications network. The network to which interface 40 connects may be a data network such as the Internet or a private packet switched data network.

In the case of an NPS, the decision to stop supplying power from a battery, under conditions of battery cell voltage or temperature, which are dubious but not definitively harmful to the battery, may be made either at a remote central decision station of the telecommunications service provider or as a result of an algorithm (operating in interface 40 or one of the controller in battery 15) that takes into consideration the operational state data (obtained by communication via the interface 40) of other battery units connected in parallel with the battery 15. If the battery 15 is not critical in maintaining service of the telecommunications equipment, a preferred, but perhaps optional shut-down should be done.

Operational Concepts

Figure 5 shows the NPS battery system connected between telecommunications equipment and a grid power rectifier. The battery and controller system is composed of the battery itself with a power switch (Sw_{power}), heater, heater control switch (SW_{heater}) and three sensors to monitor the switch voltage and current and battery temperature. As an example, the battery may be composed of 9

cells connected in series, in order to provide a maximum voltage of 28 Volts/Battery (V_{cells}= 3.1 volts).

To obtain the required performance and working conditions, the battery heater is used to maintain internal temperature to particular temperatures that are more suitable for best battery performances, such as either 40°C (floating temperature) or at 60°C (charging temperature) depending on the battery operating mode. It has to be noted that the temperatures used in the present application are provided only as an example and do not limit the scope of the present invention. Other temperatures or ranges of temperatures may be used as well. For example, a system using more than two different temperatures may use the same principle of the present invention.

As shown in the state diagram of Figure 6, when putting the battery into service, the battery temperature is brought up to 60°C to recharge the battery. When the battery is fully recharged, it goes into floating mode and the battery temperature is lowered to 40°C. When a power failure occurs, the battery is maintained at 40°C for the first 30 minutes and then it goes into hot power failure mode and the temperature is raised to 60°C.

The battery remains in service as long as it is connected, otherwise it returns to standby mode. Furthermore, during a power failure the battery stays in service as long as the internal voltage of each cells is higher than 2 volts, the temperature is below 80°C or current is lower than the short circuit condition. As soon as one cell voltage reaches 2 volts, the power and heater switch are opened and the battery returns to standby mode until power comes back on to repeat the cycle.

Initially, the NPS software starts in standby mode and only proceed to the following operating modes when connected. As shown in Figure 6, the transition from one state to the other is governed by specific events and/or operational conditions.

The *Short-circuit* and *overtemperature* modes are associated with failure conditions. In *standby* and *cold* modes, battery power is off (SW_{power} is opened) and in all other modes battery power is on (SW_{power} is closed).

The over-temperature detection is simply done by monitoring the battery internal temperature and the short-circuit by monitoring the status of the power

switch. Since the power switch is equipped with a sensing circuit that automatically opens the switch whenever the current exceed 50 Amps. After the power switch is closed, whenever the software detects that the power switch has been opened by the sensing circuit, it goes directly into short-circuit mode.

In *standby* mode, the NPS circuit card waits to be put into service (connected) and both the battery and heater switches are kept open In this mode, the software monitors the voltage at the switch (V_{switch}) and if the V_{switch} reading is:

Negative, meaning that the rectifier is connected to the battery and that battery voltage is lower than rectifier voltage, the software goes to *cold* mode;

Zero, meaning that the battery is either not connected or the rectifier voltage is equal to battery voltage, the software momentarily closes the heater to verify the resulting voltage at the switch. If V_{switch} remains zero, the rectifier is connected to the battery and the software goes to *cold* mode. Otherwise, the battery is standalone and the software remains in *standby* mode;

Positive, meaning that the battery is connected but no external power is applied to the battery, the software remains in *standby* mode if the temperature is equal or above 40°C the battery switches into power fail mode.

In *cold* mode or warm-up mode, the battery power switch is keep opened and the heater is turned on. The warmed up process is used to bring battery temperature to 60 °C before recharging. When exiting *cold* mode, a verification must be done to determine if a short-circuit condition already exist before trying to close the battery power switch.

In *charging* mode, the power switch is closed and battery temperature is kept at 60°C. The battery is recharged until its voltage reaches the voltage of the rectifier (i.e. $V_{switch} = 0$) . When the battery is fully recharged, the battery temperature set point is set to 40 °C and the battery goes into *floating* mode. While charging the battery:

If a power failure occurs, since the battery temperature is already at 60 °C, the software goes directly into *hot power failure* mode;

If the battery is disconnected, it returns to *standby* mode.

In the floating mode, the power switch is closed and battery temperature is maintained at 40°C. The battery stays in this mode until it is either disconnected or until a power failure, a short-circuit or an over temperature condition occurs.

The software modules of the controller, continuously monitors the voltage and current at the switch and whenever the current becomes greater than 0, either the battery has been disconnected or a power failure has occurred. By turning the heater off, if the current falls to zero, the battery was disconnected and the software goes into standby mode. Otherwise, if the current remains greater than 0, the software goes into power failure mode.

In the power failure mode, the power switch is maintained closed and the battery temperature is kept at 40°C. The battery enters in this mode as soon as rectifier power is lost. The battery stays in this mode for no more than 30 minutes or until rectifier power is restored, or the temperature reaches 80°C, or the battery is disconnected, or the voltage at any individual cells falls at 2 volts or below, When the 30 minutes delay as been reached, the battery temperature set point is raised to 60°C and the battery goes into *hot power failure* mode. When power is restored, the battery returns directly to *charging* mode. If the battery is disconnected or the cell voltage falls at 2 volts or bellow, the heater and power switches are opened and the battery goes into *standby* mode.

In the hot power failure mode, the power switch is maintained closed and the battery temperature is kept at 60°C. The software remains in this mode for as long as power is not restored, or the battery is disconnected, or until one of the cell voltages reaches 2 Volts, or if an over-temperature or short-circuit condition has been detected. When power is restored, the battery goes directly to charging mode.

In the short-circuit mode, the power switch was automatically opened by the over current sensing circuit and heater is turned off. The battery remains in this mode for as long as the short-circuit condition is not corrected. When corrected, it returns to *cold* mode.

Referring to Figure 5, with a short-circuit on the outside post of the battery, the voltage reading at the switch is equal to the battery voltage. As long as the voltage reading remains greater than zero, the software remains in short-circuit mode. When the voltage becomes null, the software returns to cold mode.

Whenever battery temperature reaches 80 °C, the battery gets into the over temperature mode and its power switch is open, the heater is turned off and the software goes into *over temperature* mode. The battery stays in this mode for as long as battery temperature is over 40 °C. When it reaches 40 °C or below it goes into *standby* mode.

Figure 7 shows the NPS entity relationship. The NPS software interfaces with the battery switch, cell's voltage sensors and heating system. It also provides a user interface to command and control the battery operation and to transmit battery monitoring information.

The NPS battery system uses a serial interface to communicate with external devices. Using script commands, it is possible to query for information or to change software functional parameters.

The battery power switch (SW_{power}) is activated, opened or closed, by software except when a short circuit condition is present then an electronic circuit will override the software command. When closed, a sensing circuit (hardware) monitors the current that pass through the switch, and it automatically opens the switch whenever the current exceed 50 Amps. The sensing circuit also returns the status of the switch (on/off), the voltage and the current. The status is a digital input value, the current and voltage are analog values between 0 and 5 volts.. Both signals are fed to an A/D converter channel to be read by software.

The heater is used to regulate the internal battery temperature to the desired operating level according to the mode of operation. In *standby* the heater switch is turn off/on to determine the presence of the rectifier or a load. In *short-circuit* and *over temperature* modes the heater is turned off In *cold, floating* and *power failure* modes, the temperature set point is 40 °C. In *charging* and *hot power failure* modes the temperature set point is 60 °C.

The NPS battery system is composed of 9 cells connected in series The output voltage of each cell is fed to an analog multiplexer and from the multiplexer to a A/D converter. Meaning that the software can measure the output voltage of each individual cell by selecting the appropriate channel on the multiplexer and by reading the conversion result at the A/D converter.

The software continuously monitors each cells and whenever the voltage of any cells reaches 2 volts, the battery power switch and the battery is returned in standby mode.

The NPS system may be based on the 68HC11F1 micro-controller from Motorola. The micro-controller may be used in expanded mode and may use the following 68HC11F1 resources:

- 24 I/O ports as an 8 bits data and 16 bits address buses (64 K address space);
- 512 bytes EEPROM;
- 1024 bytes of RAM;
- Asynchronous Serial Communication Interface (SCI) (full duplex, NRZ);
- Synchronous Serial Peripheral Interface (SPI);
- 14 I/O ports;

As shown in Figure 8, the following resources are added to the 68HC11F1 for the NPS battery system:

- 32 Kbytes of RAM;
- 16 channel multiplexer;
- 12 bits A/D converter;
- Full duplex current loop interface adapter circuit;
- Battery switch circuit;
- Resistance Temperature Detector (RTD).

Operating System Services and Hardware Resources

The NPS software does not rely on any operating system. It uses interrupt driven events to switch from task to task. The two sources of events are the SCI communication and the real-time clock interrupts.

The NPS software uses the real-time clock as a task scheduler for the monitoring of battery parameters and mode supervision.

The 68HC11 bootstrap mode is used to download a program into the internal 68HC11 1 KBytes RAM. When the downloading process is completed, the 68HC11 automatically starts the execution of that program.

For the NPS project, this mode is used to download a utility program to load the application into the 32 Kbytes non-volatile static RAM memory. For this purpose,

the bootstrap software initializes the communication controller and sets the configuration of the 68HC11 I/O pins to the appropriate conditions. After the initialization process is completed, the download utility sets the SCI in receiving mode and waits for the application program download files. The download file format must be in Motorola S1 codes.

After the application program has been downloaded into memory, we remove the bootstrap mode and reset the board to start the application.

The extended mode is used to run the NPS application software. This mode provides a non-multiplex 16 bits address bus and 8 bits data bus. In addition, the software requires the use of:

- Port D bits 4,3,2 for the synchronous SPI transfer;
- Port D bits 2-1 for SCI communication;
- Real-time Timers;
- Program chip select (PG 7);
- Input/Output ports (PG 5-0 and PA);

Dependencies Description

Figure 9 shows the data flow diagram the NPS software components.

The read cell voltages function uses the analog multiplexer to select a given battery cell and the 12 bits A/D converter to obtain the voltage reading. When called, this function reads the 10 cell voltages and sends the result over the SCI interface. Furthermore, if the voltage reading of any cells is lower or equal to 2 volts, an alarm is raised to signal faulty condition.

The switch circuit provides a feedback of its status (on/off), voltage and current. The status is obtained by reading the input port PA-2 and the switch voltage, and current are obtained by 12 bits A/D conversion on the multiplexer channels 10 and 11 respectively.

The control heater function is used to keep the battery temperature at a desired level. It receives a temperature set point and a dead band value. Whenever the temperature is lower or equal to the temperature set point minus the dead band value, the heater is turned on. On the other end, if the temperature is higher or equal to the temperature set point plus the dead band value the heater is turned off.

The control heater function obtains the temperature reading from the 12 bits A/D conversion on multiplexer channel 12. The temperature signal comes from a Resistance Temperature Detector (RTD) circuit that provide a voltage reading proportional to the temperature level.

The control environment function monitors the battery parameters and sets the battery operating mode according to the voltage and current readings from the power switch. It also monitors the over-temperature and short-circuit conditions and controls the power and heater switches accordingly.

The user interface function provides a series of control and query commands to change working parameters or to query for monitoring information. The set switch function is used to control the battery power switch. When activated, the function reads the feedback from the power switch sensing circuit to confirm the status of the switch with the issued command.

Battery Controller Software Modules

There is a plurality of software modules that performs various tasks on the battery controller card. As an example, some of this modules are described in the following paragraphs.

With logical 1's on 68HC11 input pins MODA and MODB, the micro controller automatically starts in expanded mode. Meaning that I/O ports B, F and C are configured as 16 bits address bus and 8 bits data bus respectively and all other I/O ports are configured as input ports.

This function initializes output pins on ports A and G and sets their respective value according to the following:

PA 7-4	Multiplexer channel selector	0
PG 3-2	Power Switch Control	OFF (1-0)

The battery controller acquisition system is based on external 12 bits A/D converter having 16 channels analog multiplexer. The external A/D converter uses synchronous interface, compatible with Motorola SPI communication protocol, to receive and transmit data.

The battery cells are connected to the first 10 channels of the 16 channels analog multiplexer MAX306 and the MAX306 output is sent to the A/D converter (LTC1286) for signal conversion. Cells 1 to 9 are connected to channels 0 to 8. The channel selection is done by the output port PA-4 to PA-7. When a channel is selected, a delay of at least 5 ms shall be provided for the corresponding signal to stabilize before the A/D conversion.

The voltage and current signals, for the battery power switch relative voltage and drawn current, are also sent to the analog multiplexer for conversion by the A/D converter (LTC1286). The switch voltage is obtained on channel 11 and the switch current on channel 11.

The get switch voltage and current function selects each channel for conversion and records the result from the A/D converter in two variables.

The temperature is obtained through the RTD sensor located inside the battery. The RTD value is converted into a voltage equivalent and sent to the analog multiplexer channel 12. The temperature is obtained by converting the RTD signal with the A/D converter (LTC1286). The temperature reading is returned as is (not translated) to the calling routine.

The user interface function, processes messages received on the communication channel and returns polling request.

The Scheduler is connected to the 68HC11 real-time timer interrupt. The Scheduler verifies the battery parameters and set the software into the appropriate operating mode according to the state diagram shown in Figure 6. With the 8 MHz crystal, the real-time timer is set to generate an interrupt (timer tick) every 32.77 ms, meaning that the Scheduler is executed at a rate of about 30 Hz. Each time Scheduler handler is executed it increment timer tick counts to a desired delay. When the delay is reached, the corresponding function (or task) is executed and the count is reset to restart the process.

Battery Controller Remote Access and Control

The battery controller previously described may be reached via a network, such as the internet network in order to be remotely controlled from a remote computer system. Figure 7 shows a general representation of a plurality of battery

controllers which are accesses and controlled from a remote data acquisition, control and monitoring station.

Various protocols, such as TCP/IP or UDP may be used in order to remotely access the battery controllers via a network. The communication link established between the controlling station and the battery controllers provide data security by using encryption and password protection. The UPS control unit may also provide data recording capability for FTP transfer, when requested by the user. Other communication facilities may be used as well for remote accessing the battery controllers. Using the internet network or other widely spread network, data acquisition, control and monitoring systems may be located anywhere.

The overall NPS system, as shown in Figure 12, is composed of the NPS communication controller that provides the communication link with a remote node, the NPS current limiter that provide the monitoring functions for a string of two batteries and the NPS Battery controller that provide the monitoring and control required on each battery.

The remote NPS Monitoring Station shall obtain log file recorded by the NPS Communication Controller and provide the monitoring functions to display the histogram and current status of an NPS System.

It has to be noted that Figure 12 only gives an example of NPS system configuration. The number of battery controllers as well as the number and type of NPS current limiters may vary from one application to another, depending on the output voltage of the batteries.

A portable NPS Service station may be used by a battery controller administrator to monitor locally the status of an NPS System and to provide the functionality required to service the NPS system components. In particular, it shall be used to:

- Update software/firmware;
- Modify operating parameters;
- Download NPS System log file from the NPS Communication Controller.

Eventually, the two stations (i.e. the portable and the remote stations) may be set up in order to perform the same tasks.

A local computer station is needed to serve as a local communication server at the battery controller location, as better shown in Figure 12. This UPS communication controller is used as an interface between the battery controller and the remote acquisition, control and monitoring station. Its task is to send and receive data over the communication network (internet or other) to and from the remote station. As an example, but not restricted to, the UPS communication controller may have the following features:

- use a Windows 95/NT operating system;
- have a Lonworks FTT-10 78 kbits communication interface;
- provide Lontalk file transfer services;
- have a large amount of disk space for data logging and program space.

Although the present invention has been described with reference to a preferred embodiment, it is to be understood that the present description is intended to teach a preferred embodiment and not to limit the scope of the invention from encompassing variant embodiments as defined in the appended claims.

CLAIMS:

1. A battery controller system for a metal and solid electrolyte battery having a number of cells housed arranged in a housing, the controller comprising:

a plurality of temperature sensors arranged to detect a temperature of said cells;

a plurality of heating elements arranged to heat said cells;

a heating element controller receiving signals from said temperature sensors and controlling a current supplied to said heating elements so as to maintain each one of said cells at a predetermined temperature; and

a power mode controller detecting a demand for power from the battery and setting said predetermined temperature in response to a level of power and/or an amount of energy to be supplied from or to said battery, the power mode controller setting at least a floating temperature, a charging temperature, and a power supply temperature.

2. The controller system as claimed in claim 1, wherein said heating elements comprise sheet heating elements provided between flat prismatic cells.

3. The controller system as claimed in claim 2, wherein said heating elements comprise plastic sheets having at least one printed circuit resistive heating element thereon.

4. The controller system as claimed in claim 3, wherein said plastic sheets are made of Kapton™.

5. The controller system as claimed in claim 2, wherein said battery comprises a stack of flat prismatic cells, said temperature sensors are located at extremities of said stack and near a middle of said stack, and said heating elements are provided between at least every other one of said cells, said heating element controller controlling a supply of current to said heating elements independently for said extremities and said middle of said stack.

6. The controller system as claimed in claim 3, wherein said battery comprises a stack of flat prismatic cells, said temperature sensors are located at extremities of said stack and near a middle of said stack, and said heating elements are provided between at least every other one of said cells, said heating element controller controlling a supply of current to said heating elements independently for said extremities and said middle of said stack.

7. The controller system as claimed in claim 1, further comprising :

a voltage sensor circuit detecting at least a voltage of said battery at said power connection;

a battery performance evaluator circuit interpreting signals from said voltage sensor and generating evaluation signals;

a telecommunications circuit relaying said evaluation signals to a network.

8. The controller system as claimed in claim 1, further comprising :

a current sensor detecting a current supplied by said cells during use;

means for interpreting said current for determining whether an over current condition exists; and

means for disconnecting said battery from said power connection in response to the over current condition and for automatically reconnecting said battery when an over current condition ceases.

9. The controller system as claimed in one of claims 1-8, wherein said battery is a lithium-polymer battery.

10. A battery controller system for a metal and solid electrolyte battery having a number of cells connected in series and a power connection, the controller comprising :

a voltage sensor detecting a voltage of each one of said cells during use;

means for interpreting said detected voltage and for determining whether any one of said cells is susceptible to damage by continued use; and

means for disconnecting said battery from said power connection in response to determination that one of said cells may be damaged.

11. The controller system as claimed in claim 10, further comprising :

a voltage sensor circuit detecting at least a voltage of said battery at said power connection;

a battery performance evaluator circuit interpreting signals from said voltage sensor and generating evaluation signals;

a telecommunications circuit relaying said evaluation signals to a network.

12. The controller system as claimed in claim 10, further comprising :

a current sensor detecting a current supplied by said cells during use;

means for interpreting said current for determining whether an over-current condition exists; and

means for disconnecting said battery from said power connection in response to the over current condition and for automatically reconnecting said battery when an over current condition ceases.

13. The controller system as claimed in claim 10, further comprising :

a plurality of temperature sensors arranged to detect a temperature of said cells;

a plurality of heating elements arranged to heat said cells;

a heating element controller receiving signals from said temperature sensors and controlling a current supplied to said heating elements so as to maintain each one of said cells at a predetermined temperature; and

a power mode controller detecting a demand for power from the battery and setting said predetermined temperature in response to a level of power to be supplied from or to said battery, the power mode controller setting at least a floating temperature, a charging temperature, and a power supply temperature.

14. The controller system as claimed in one of claims 9-13, wherein said battery is a lithium-polymer battery.

15. The controller system as claimed in claim 14, wherein said heating elements comprise sheet heating elements provided between flat prismatic cells.

16. The controller system as claimed in claim 15, wherein said heating elements comprise plastic sheets having at least one printed circuit resistive heating element thereon.

17. The controller system as claimed in claim 16, wherein said plastic sheets are made of Kapton™.

18. The controller system as claimed in claim 15, wherein said battery comprises a stack of flat prismatic cells, said temperature sensors are located at extremities of said stack and near a middle of said stack, and said heating elements are provided between at least every other one of said cells; said heating element controller controlling a supply of current to said heating elements independently for said extremities and said middle of said stack.

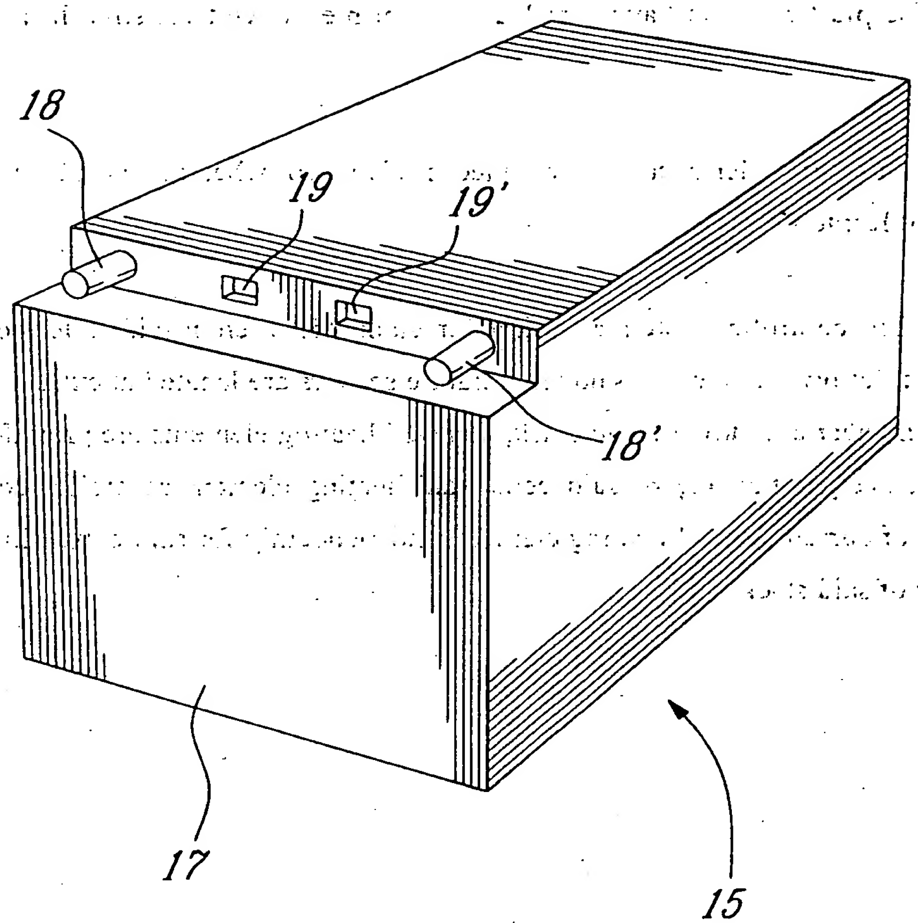


FIG. 1

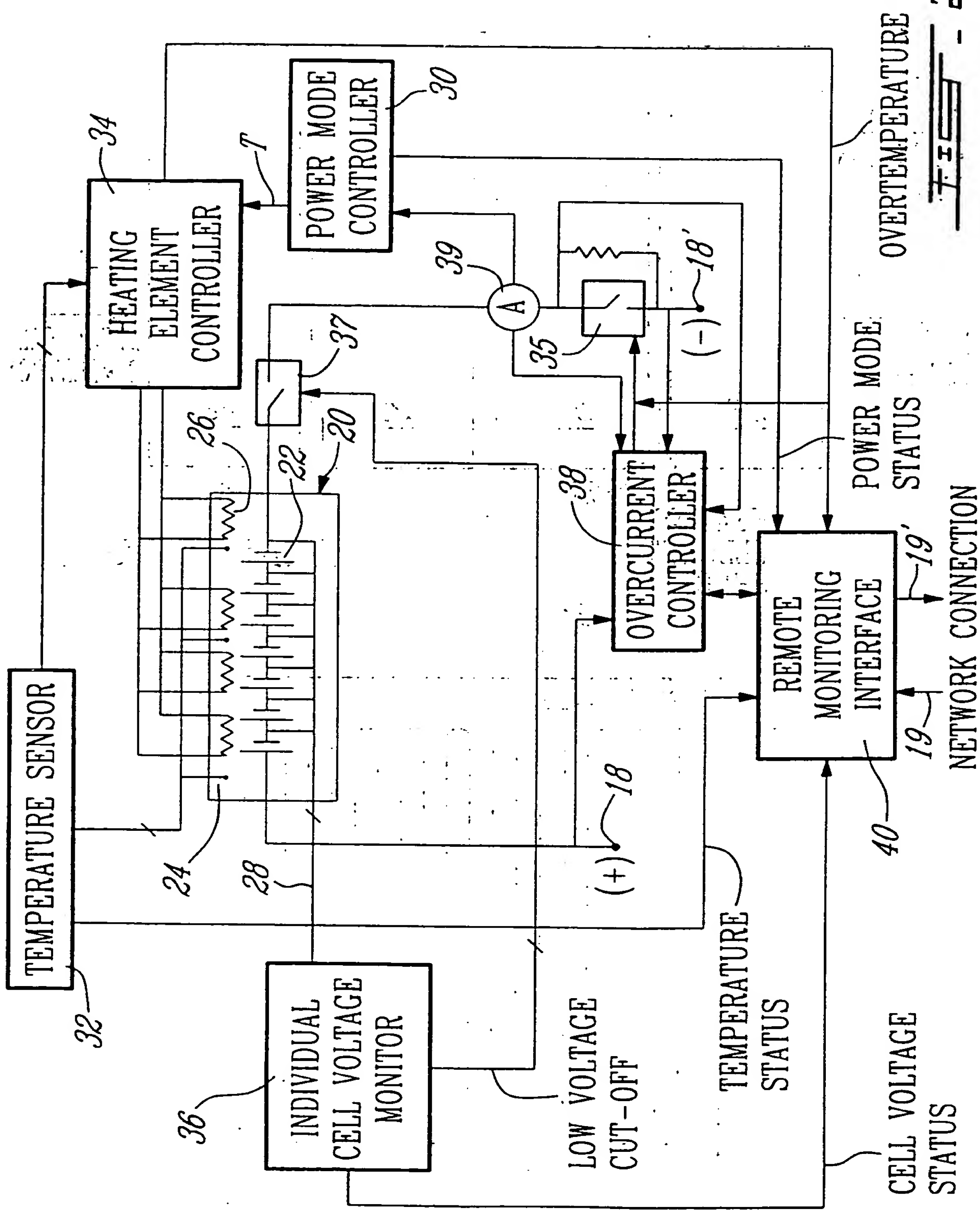

POWER MODE CONTROLLER
30
HEATING ELEMENT CONTROLLER
34
T
39
A
35
18'
(-)
37
26
22
20
38
OVERCURRENT CONTROLLER
REMOTE MONITORING INTERFACE
19'
19
40
NETWORK CONNECTION
POWER MODE STATUS
OVERTEMPERATURE
TEMPERATURE SENSOR
32
24
28
18
(+)
INDIVIDUAL CELL VOLTAGE MONITOR
36
LOW VOLTAGE CUT-OFF
TEMPERATURE STATUS
CELL VOLTAGE STATUS

FIG - 2

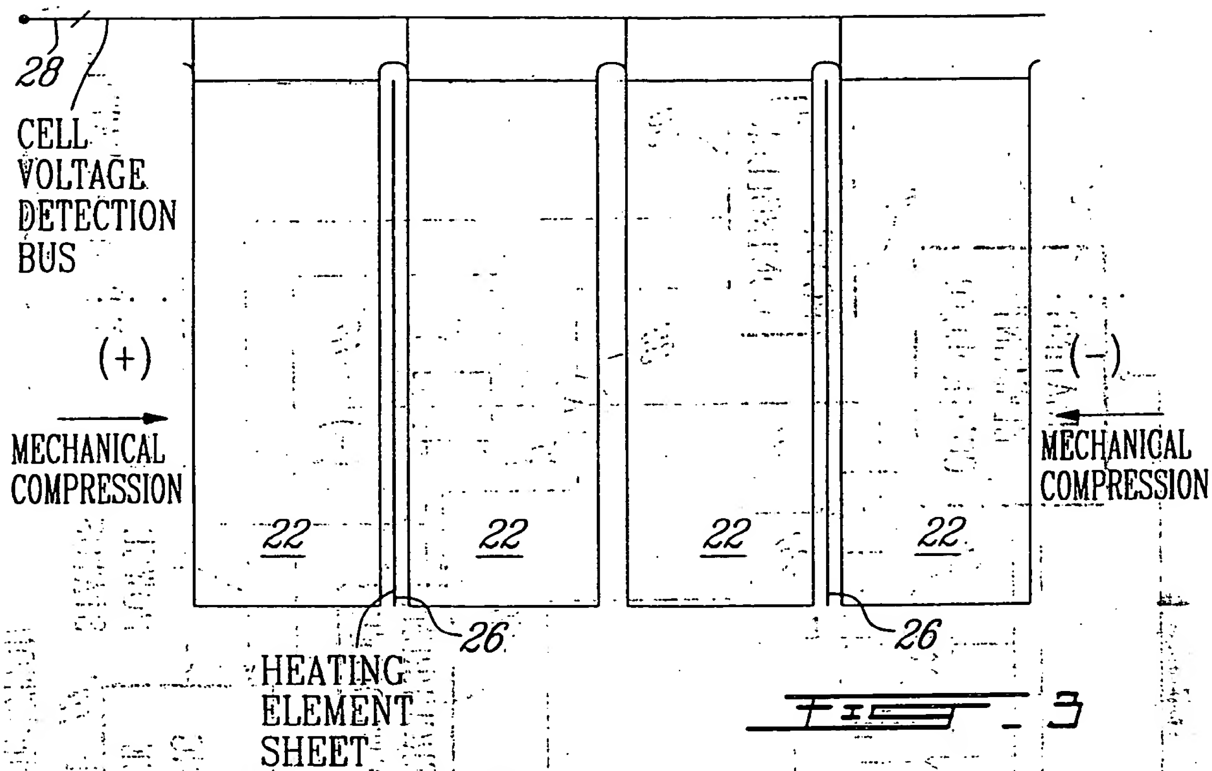

28
CELL VOLTAGE DETECTION BUS
(+)
MECHANICAL COMPRESSION
(–)
MECHANICAL COMPRESSION
22
22
22
22
26
26
HEATING ELEMENT SHEET

FIG. 3

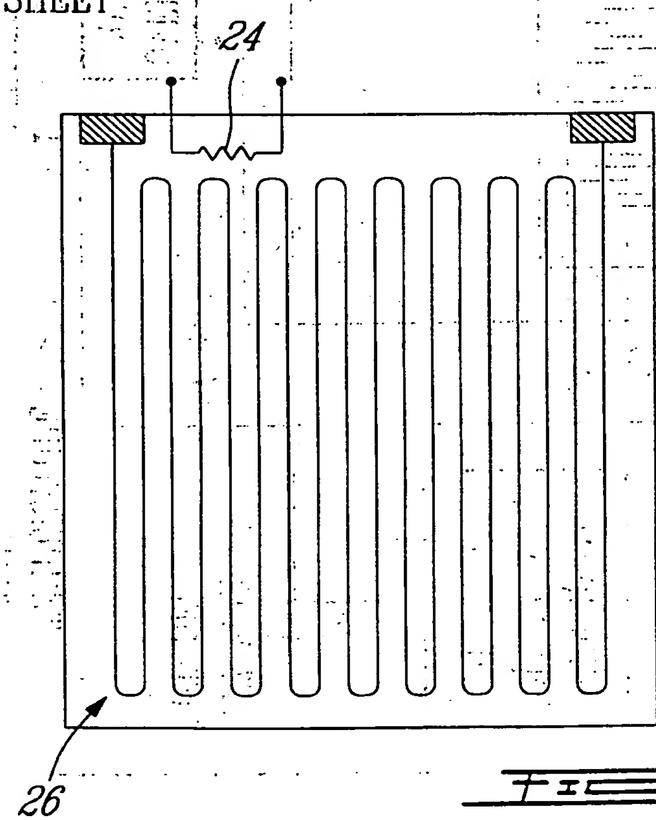

24
26

FIG. 4

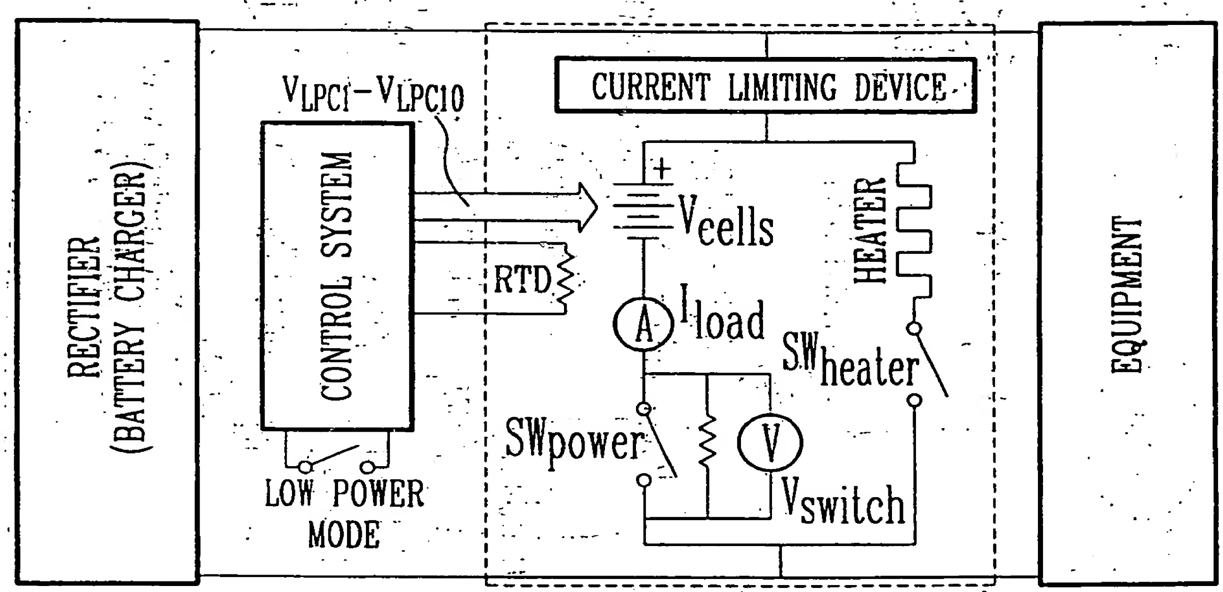
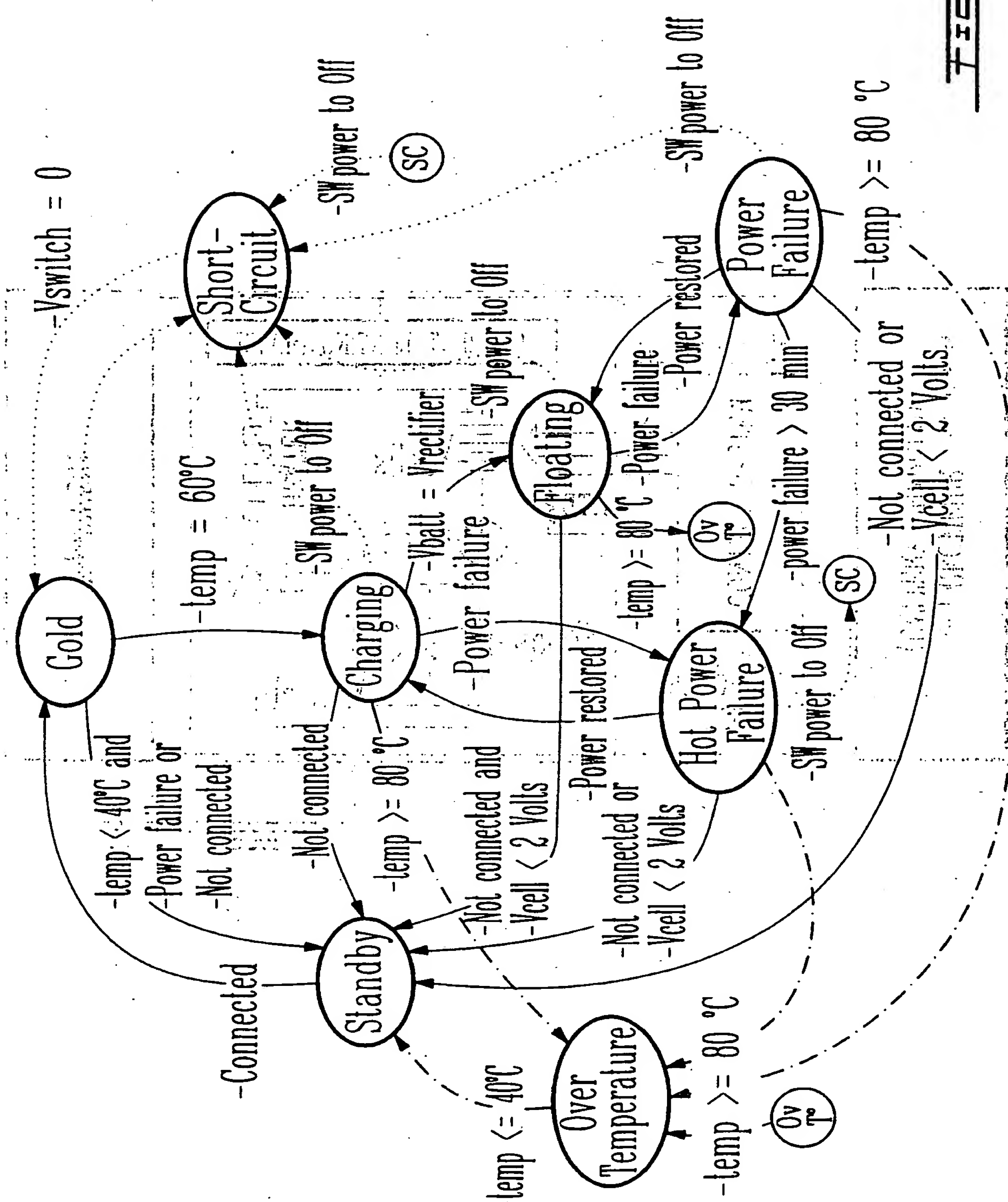

RECTIFIER
(BATTERY CHARGER)
VLPC1-VLPC10
CONTROL SYSTEM
LOW POWER
MODE
CURRENT LIMITING DEVICE
Vcells
RTD
Iload
A
HEATER
SWheater
SWpower
V
Vswitch
EQUIPMENT

FIG. 5

FIG. 6


Cold
Charging
Floating
Short-Circuit
Power Failure
Hot Power Failure
Standby
Over Temperature
-Vswitch = 0
-SW power to Off
SC
-SW power to Off
-temp = 60°C
-SW power to Off
-Vbatt = Vrectifier
-Power failure
-SW power to Off
-Power restored
-Power failure
-Power restored
-Power failure
-temp >= 80 °C
OvT
-power failure > 30 min
-temp >= 80 °C
-Not connected or
-Vcell < 2 Volts
-SW power to Off
SC
-Power restored
-temp < 40°C and
-Power failure or
-Not connected
-Not connected
-temp >= 80 °C
-Not connected and
-Vcell < 2 Volts
-Not connected or
-Vcell < 2 Volts
-Connected
-temp <= 40°C
-temp >= 80 °C
OvT

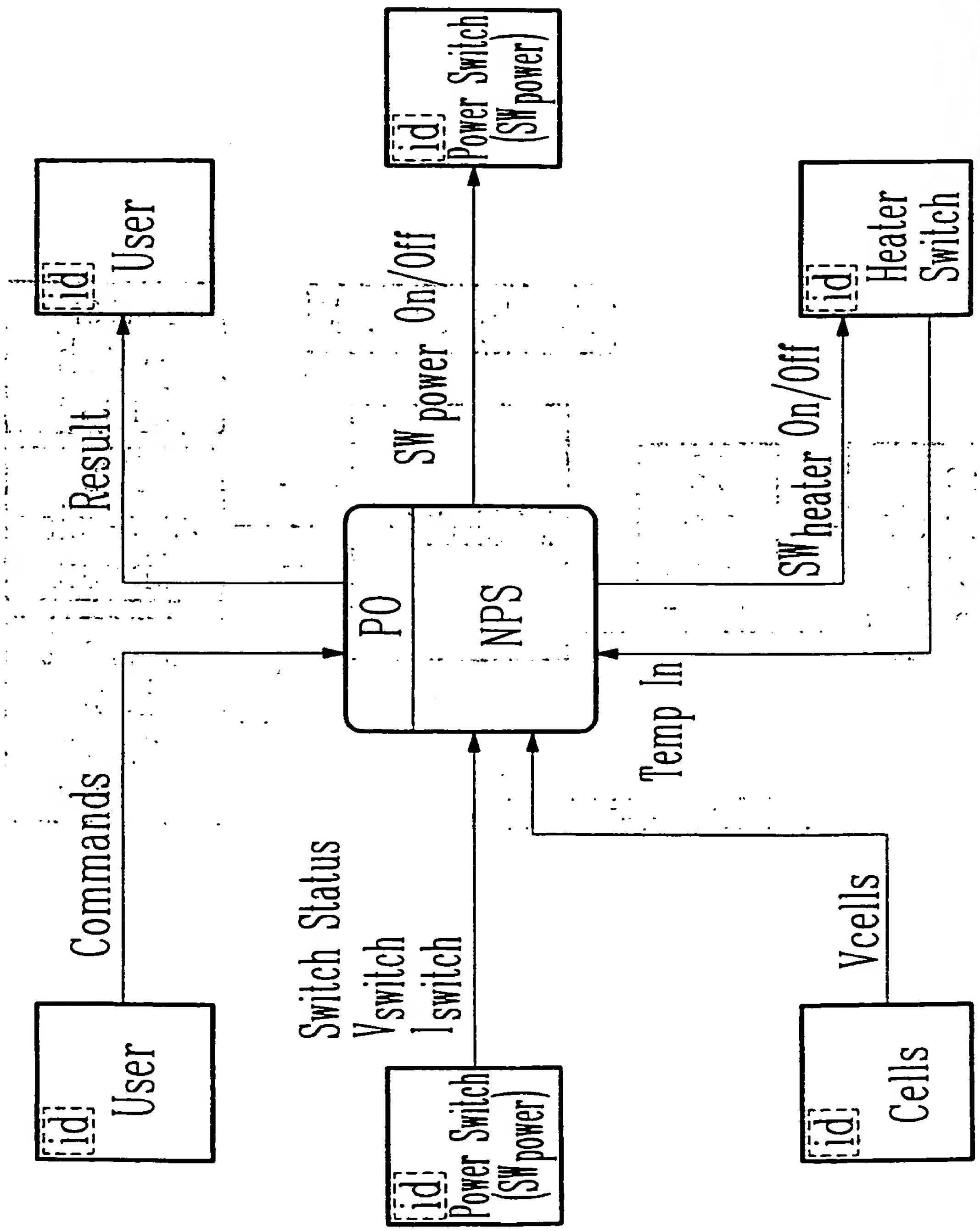

id
User
Result
Commands
id
User
id
Power Switch
(SW_{power})
SW_{power} On/Off
PO
NPS
Switch Status
V_{switch}
I_{switch}
id
Power Switch
(SW_{power})
id
Heater
Switch
SW_{heater} On/Off
Temp In
Vcells
id
Cells

FIG. 7

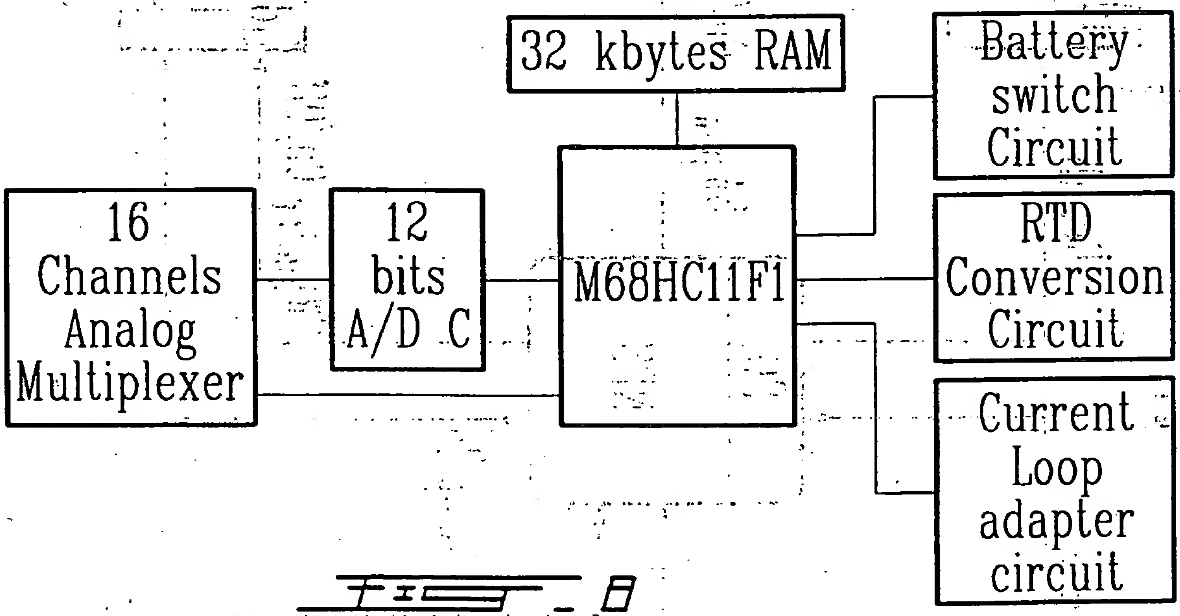

32 kbytes RAM
Battery switch Circuit
16 Channels Analog Multiplexer
12 bits A/D C
M68HC11F1
RTD Conversion Circuit
Current Loop adapter circuit

FIG. 8

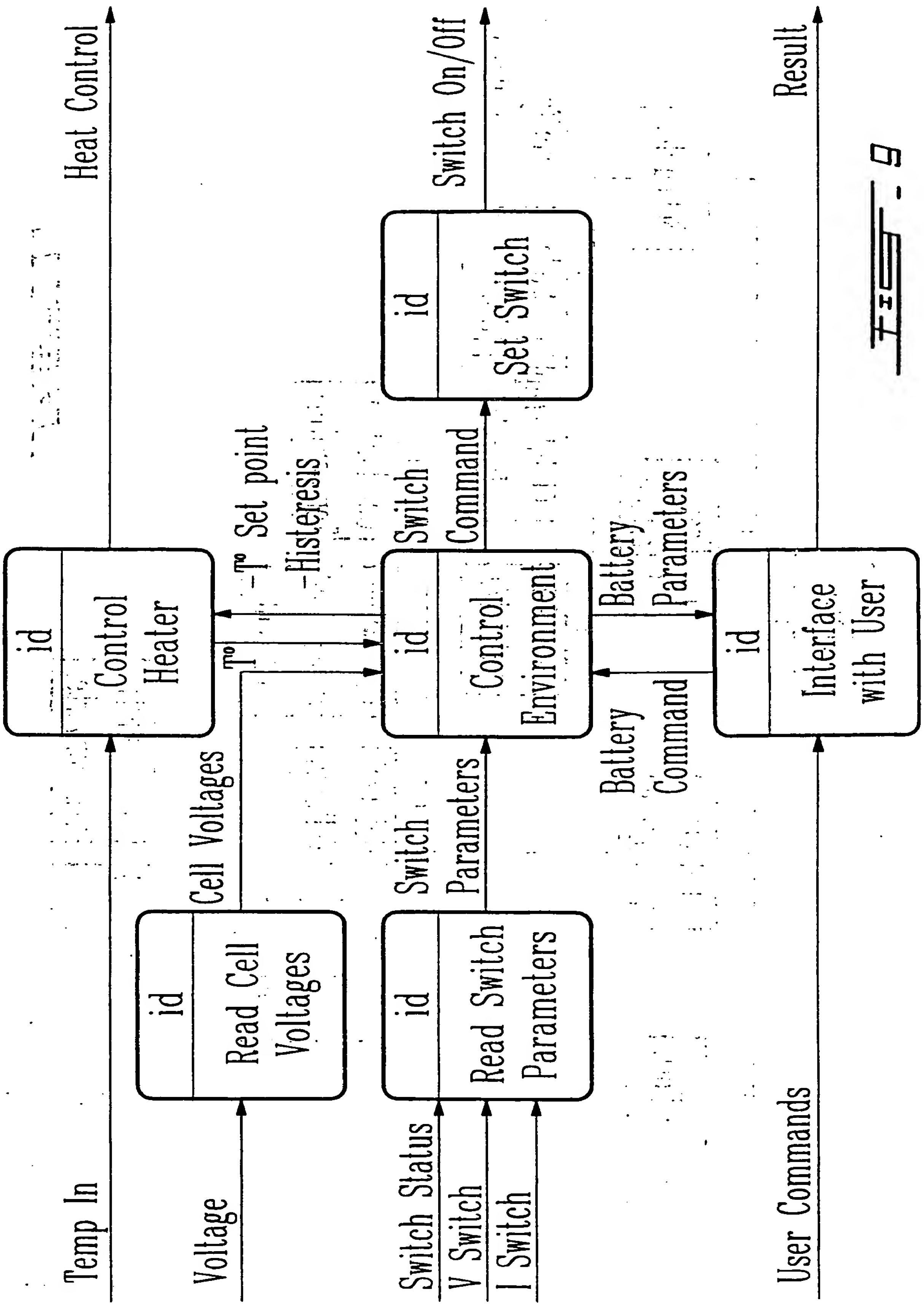

Heat Control
Switch On/Off
Result
id
Set Switch
-T° Set point
-Histeresis
Switch
Command
Battery
Parameters
id
Control
Heater
T°
id
Control
Environment
id
Interface
with User
Cell Voltages
Switch
Parameters
Battery
Command
id
Read Cell
Voltages
id
Read Switch
Parameters
Temp In
Voltage
Switch Status
V Switch
I Switch
User Commands

FIG - 9

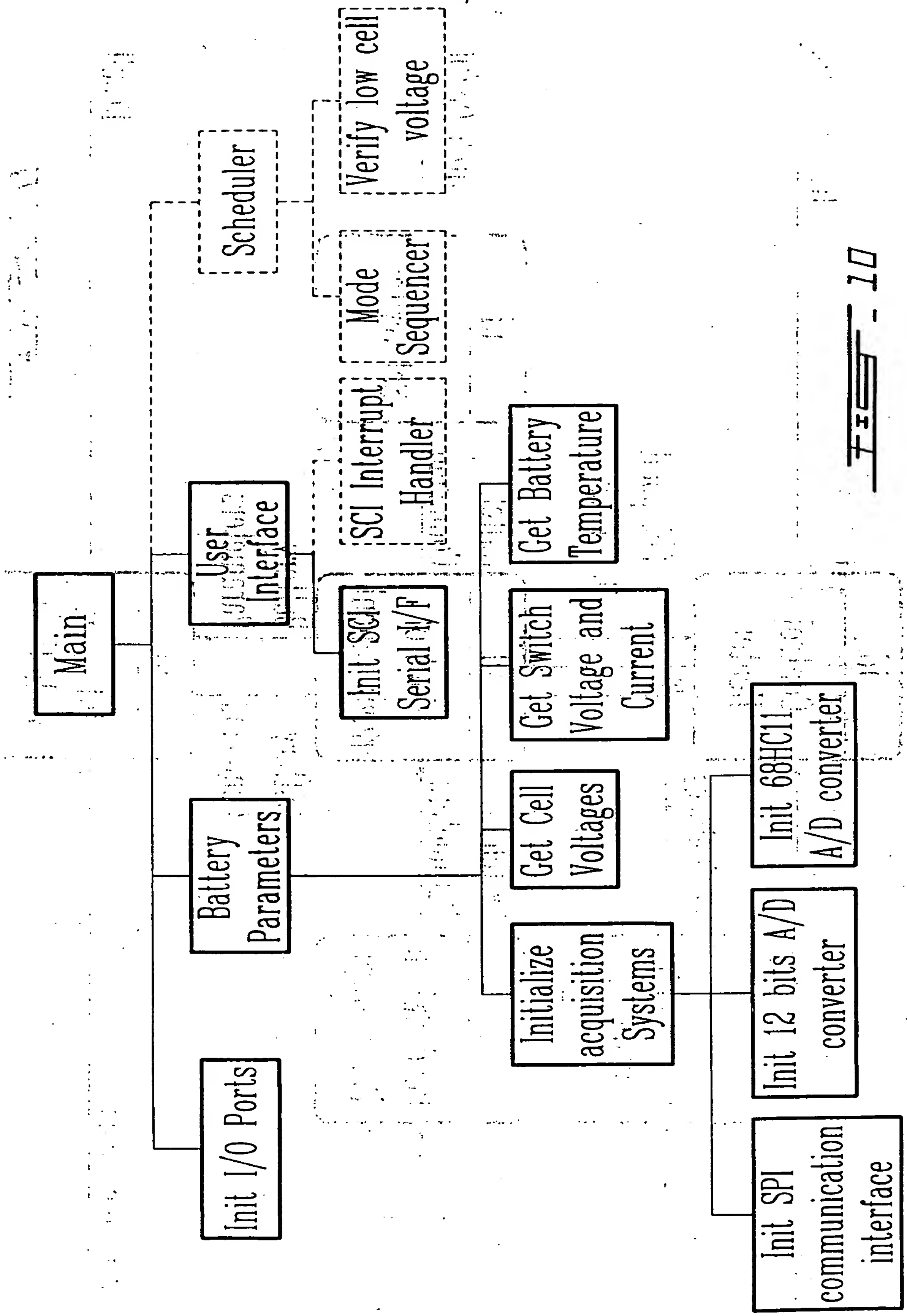

Main
User Interface
Battery Parameters
Init I/O Ports
Scheduler
Verify low cell voltage
Mode Sequencer
SCI Interrupt Handler
Init SCI Serial I/F
Get Battery Temperature
Get Switch Voltage and Current
Get Cell Voltages
Initialize acquisition Systems
Init 68HC11 A/D converter
Init 12 bits A/D converter
Init SPI communication interface

FIG. 10

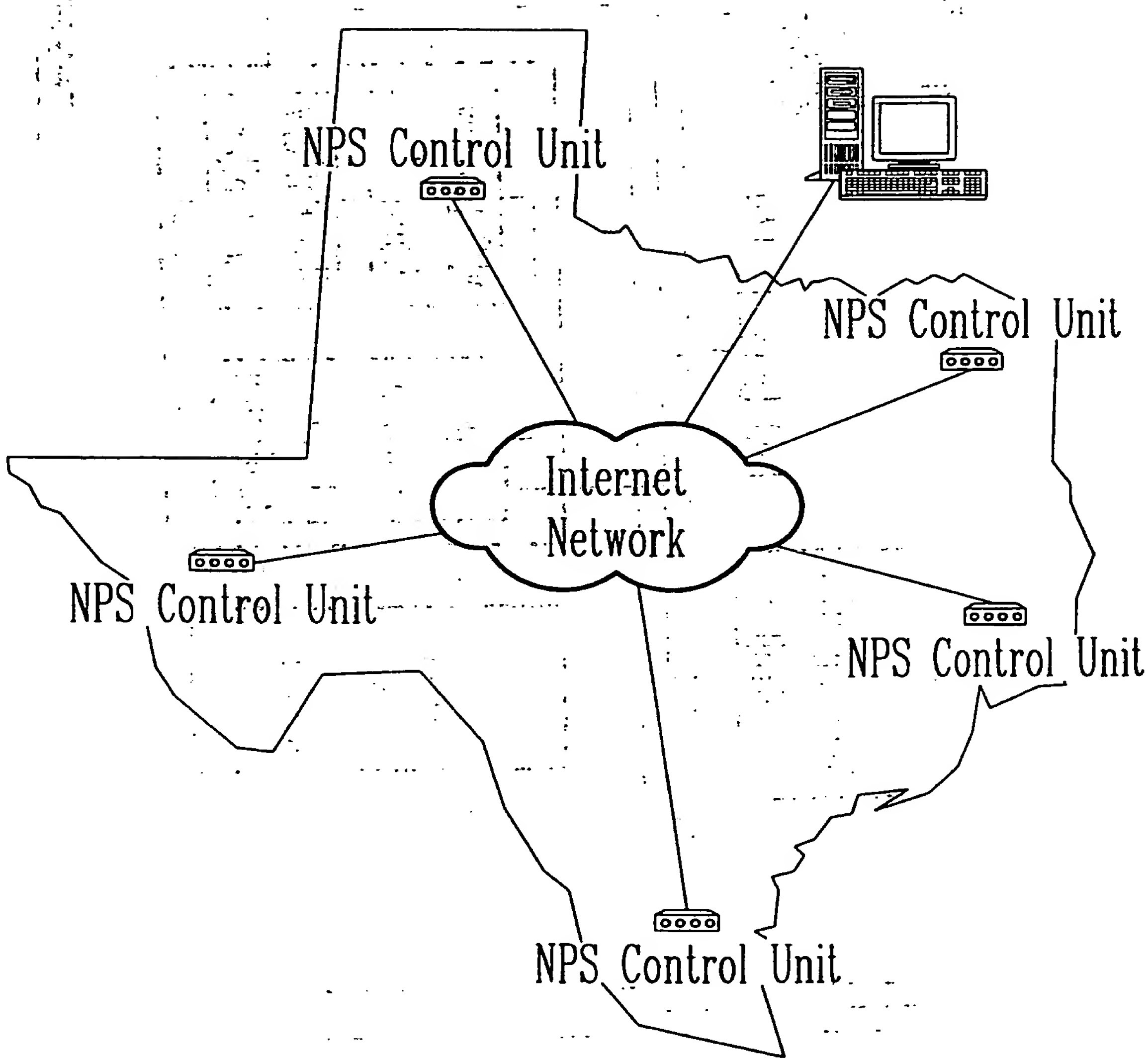

NPS Control Unit
NPS Control Unit
Internet Network
NPS Control Unit
NPS Control Unit
NPS Control Unit

FIG. 11

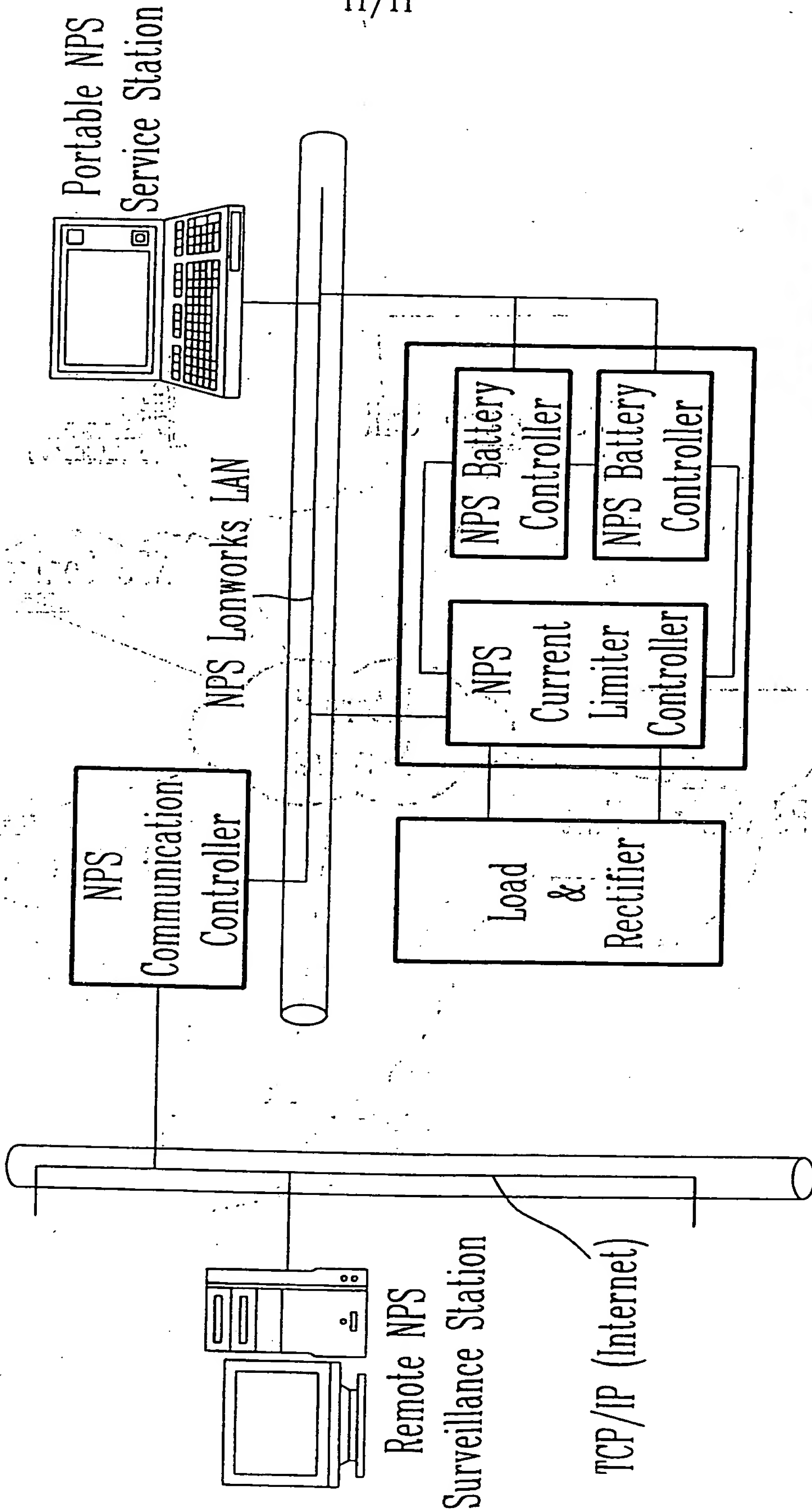

Portable NPS Service Station
NPS Lonworks LAN
NPS Battery Controller
NPS Battery Controller
NPS Current Limiter Controller
NPS Communication Controller
Load & Rectifier
Remote NPS Surveillance Station
TCP/IP (Internet)

FIG - 12

INTERNATIONAL SEARCH REPORT

International Application No
PCT/CA 98/01144

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 H01M10/50 H01M10/48 G01R31/36 H02J7/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 H01M G01R H02J

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 96 17397 A (RASMUSSEN KIM ;REIPUR JOHN (DK); CHARTEC LAB AS (DK); ESTATE OF TH) 6 June 1996	1,9
Y	see page 2, line 12 - page 3, line 5 see page 4, line 19 - page 5, line 10 see page 6, line 32 - page 8, line 35 see page 12, line 26 - page 19, line 26; claims 1-36 ---	2-8, 10-12
X	YUFEI CHEN ET AL: "THERMAL MANAGEMENT OF LITHIUM/POLYMER BATTERIES FOR ELECTRIC VEHICLE APPLICATION" EXTENDED ABSTRACTS, vol. 94/2, no. 16, 1 January 1992, page 129/130 XP000550765	1,9
Y	see the whole document ---	2,3,5-8, 13-16,18
	-/--	

[X] Further documents are listed in the continuation of box C

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
25 May 1999	07/06/1999

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	De Vos, L

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Inter ... onal Application No
PCT/CA 98/01144

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
Y	EP 0 512 340 A (SONY CORP) 11 November 1992 see column 3, line 14 - column 13, line 14 ---	10-18
Y	WO 95 10127 A (MOTOROLA INC) 13 April 1995 see page 4, line 11 - page 6, line 35; claims 1,2 ---	4,17
X	DATABASE INSPEC INSTITUTE OF ELECTRICAL ENGINEERS, STEVENAGE, GB Inspec No. 5484661, YUFEI CHEN ET AL: "Modeling studies on battery thermal behaviour, thermal runaway, thermal management, and energy efficiency" XP002103630 see the whole document & IECEC 96. PROCEEDINGS OF THE 31ST INTERSOCIETY ENERGY CONVERSION ENGINEERING CONFERENCE (CAT. NO.96CH35978), IECEC 96. PROCEEDINGS OF THE 31ST INTERSOCIETY ENERGY CONVERSION ENGINEERING CONFERENCE, WASHINGTON, DC, USA, 11-16 AUG. 1996, pages 1465-1470 vol.2, ISBN 0-7803-3547-3, 1996, New York, NY, USA, IEEE, USA ---	1,9
X A	DE 44 42 825 A (AABH PATENT HOLDINGS) 8 June 1995 see column 5, line 62 - column 14, line 32 ---	1 7,8, 10-13
X	PATENT ABSTRACTS OF JAPAN vol. 096, no. 009, 30 September 1996 -& JP 08 140274 A (FUJITSU LTD), 31 May 1996 see abstract ---	1
P,X	PATENT ABSTRACTS OF JAPAN vol. 098, no. 010, 31 August 1998 & JP 10 117406 A (FUJI PHOTO FILM CO LTD), 6 May 1998 see abstract ---	1,9
A	PATENT ABSTRACTS OF JAPAN vol. 014, no. 580 (E-1017), 25 December 1990 & JP 02 253571 A (JAPAN STORAGE BATTERY CO LTD), 12 October 1990 see abstract ---	2,3
A	DE 42 05 992 A (BECH JAROSLAV ;WUENSCH WILFRIED (DE)) 2 September 1993 see column 2, line 20 - column 4, line 11 ---	1

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Form PCT/ISA/210 (continuation of second sheet) (July 1992)

INTERNATIONAL SEARCH REPORT

International Application No
PCT/CA 98/01144

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
A	PATENT ABSTRACTS OF JAPAN vol. 012, no. 337 (E-657), 12 September 1988 & JP 63 098971 A (HITACHI LTD), 30 April 1988 see abstract	1
A	US 5 508 126 A (BRAUN DIETER) 16 April 1996 see column 6, line 17 - column 10, line 8; claims 1-15	1,10
A	EP 0 583 906 A (SONY CORP) 23 February 1994 see page 3, line 25 - page 4, line 21 see page 4, line 44 - page 6, line 55; claims 1-14	1,7,8, 10-13
A	WO 96 08846 A (APPLE COMPUTER) 21 March 1996 see page 8, paragraph 2 - page 26, paragraph 1	1-18
A	GB 2 282 924 A (NIPPON ELECTRIC CO) 19 April 1995 see page 9, line 5 - page 13, line 2	10-12

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/CA 98/01144

Patent document cited in search report		Publication date	Patent family member(s)			Publication date
WO 9617397	A	06-06-1996	AT	179025	T	15-04-1999
			AU	3978895	A	19-06-1996
			CN	1173242	A	11-02-1998
			DE	69509117	D	20-05-1999
			EP	0795206	A	17-09-1997
			JP	11501447	T	02-02-1999
EP 0512340	A	11-11-1992	JP	4331425	A	19-11-1992
			US	5547775	A	20-08-1996
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